

On the "Kew" Scale of Temperature and its Relation to the International Hydrogen Scale.

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In October, 1887, the International Committee of Weights and Measures adopted as the standard thermometric scale to which all temperature measurements were to be referred that of the *constant-volume hydrogen thermometer*.* When, therefore, thermometric readings are expressed on any other scale the correction to be applied to these to bring them into accord with this standard becomes of importance.

By far the majority of temperature measurements are made by means of mercury thermometers. The ideal mercury thermometer would be one which when subjected to any steady temperature would assume immediately a steady reading identical with that given by the hydrogen thermometer at the same temperature. This ideal is, as might be expected, not attained by any known mercury-in-glass thermometer, and the amount of the departure from the ideal at different temperatures depends on the particular kind of glass employed. So long ago as 1847 Regnault was aware of this fact, and showed that for several of the best thermometric glasses then in use the departure might attain as much as 10° C. above 300° C.

For many years thermometers have been verified at Kew Observatory in large numbers annually, their indications being referred to the *Kew Scale* of temperature. It has recently become a matter of interest to determine to what degree of accuracy the *Kew Scale* may be considered as identical with that of the hydrogen thermometer, and this memoir gives an account of some experiments undertaken at the National Physical Laboratory with a view to elucidate this question.

The only comparisons between Kew thermometers and the gas thermometer of which the author has been able to find a record are those by

* The resolution was as follows :—"That the International Committee of Weights and Measures adopt as the normal thermometric scale for the international service of weights and measures the centigrade scale of the hydrogen thermometer, having as fixed points the temperature of melting ice (0°) and that of the vapour of distilled water in ebullition (100°), under the normal atmospheric pressure; the hydrogen being taken under the manometric initial pressure of 1 metre of mercury, *i.e.*, at $1000/760 = 1.3158$ of the atmospheric pressure."

Balfour Stewart,* the observations of Wiebe,† the observations of Guillaume, made at the Bureau International des Poids et Mesures, and the work of Chree.‡

Of these, the first and the last are confined to determinations of the difference between the two scales at the freezing point of mercury. Chree found that at this temperature the mean departure of 20 calibrated Kew standards was $0^{\circ}45$ F., the mean temperature on the Kew scale being $-38^{\circ}35$ F., while Balfour Stewart’s value for the true temperature on the air scale was $-37^{\circ}9$ F.

Wiebe’s determinations were confined to a single thermometer, which was only divided to $\frac{1}{2}^{\circ}$ C. The composition of the glass of this instrument is given as:—

Silica	44.49	Lime	1.20
Lead oxide	33.90	Magnesia	0.67
Potash	12.26	Alumina and iron oxide..	0.35
Soda	1.54	Manganese oxide ..	0.13

He compared the instrument directly against an air thermometer between 0° and 100° C. In a *résumé* on mercury thermometry by Schloesser§ the results of Wiebe are given re-calculated as divergences from the hydrogen scale as follows:—

Temp.	Difference. $T_{\text{Eng. gl.}} - T_{\text{Hyd.}}$
10°	$+0.008^{\circ}$
20	$+0.001$
30	$+0.017$
40	-0.037
50	-0.057
60	-0.073
70	-0.079
80	-0.070
90	-0.046

These numbers are derived from a smoothed curve drawn through the observed values, and take no account of considerable irregularities, which manifested themselves at various points throughout the scale. The fact that the mercury thermometer reads *lower* than the hydrogen over nearly the whole range is pointed out by Wiebe as very unusual.

* ‘Phil. Trans.’ 1863, p. 425.

† ‘Berliner Sitz.’ 1885, p. 1021; and later, ‘Zeit. für Instr.’ vol. 10, p. 435, 1890.

‡ ‘Phil. Mag.’ vol. 45, p. 225, 1898.

§ ‘Zeit. für Instr.’ vol. 21, p. 296, 1901.

The observations of Guillaume quoted by Benoit* relate to a single English glass standard and appear to have reference to the "movable zero" method. They gave—

Temp.	Difference. $T_{\text{Eng. gl.}} - T_{\text{Hvd.}}$
0° C.	+0.000
10 	+0.007
20 	+0.005
30 	—0.004
40 	—0.012
50 	—0.021

The usual type of Kew standard thermometer is an instrument having a range from below 32° to above 212° F., and is usually divided only to 1° F. The stems are always of the solid cylindrical type, 5 to 7½ mm. in diameter, and are sometimes with, sometimes without, milk-glass backing. The capillary is always of circular section, and the diameter of the bulb is never greater than that of the stem; but large spherical bulbs were used on some of the oldest specimens. Measurement of a number of representative specimens made at various times over a period of 50 years showed the length of a division (1° F.) varied from 1 to 3 mm., and that the thickness of the division line subtended a length of stem corresponding to from 0°·04 to 0°·08 F. This type of thermometer was intended for work to an accuracy of 0°·1 or 0°·05 F.

For the purpose of this research it was thought desirable, after studying the behaviour of a number of these old thermometers, to construct new standards, having a more open scale and capable of being read to higher accuracy, and to treat these from the beginning in a definite and systematic manner.

The usual type of Kew standard is graduated so as to correct any irregularities in the calibre of the stem, this being effected by making a preliminary calibration of the tube, and appropriately lengthening or shortening the divisions throughout the scale. This is generally successful to the extent that no calibration error exceeding 0°·05 C. persists. Hence the application of a calibration correction is rendered unnecessary.

The readings of a Kew standard are always understood to apply to the thermometer in a vertical position when immersed in water up to the reading, and the instruments are always intended to be used as "fixed" rather than "movable zero" instruments. That is, the normal procedure to measure any temperature on the Kew scale would be to *first* determine the zero and *afterwards* the temperature in question, applying to the latter a

* "Détermination du Rapport du Yard au Mètre," Bur. Int. Poids et Mes., 1896.

constant correction for any deviation of the zero point from its nominal correct value, 0° C., or 32° F., and ignoring all changes of zero produced in the thermometer by exposure to the higher or lower temperature in question.

The increased sensitiveness desired in the new instruments was obtained by constructing them as is now usual for standard work so that the range between boiling and freezing points was spread over two distinct stems. Accordingly, in 1902, 12 thermometers of the solid stem type were blown by Mr. Hicks from glass furnished by Messrs. Powell from their stock, the makers assuring us that it was identical in composition with that supplied for ordinary Kew standards.

The thermometers were annealed very thoroughly according to the following scheme:—On August 19, 1902, they were heated for eight hours to temperatures varying between 260° and 290° C. During this heating the ice-points rose permanently an average of 15 mm. on the scale, *i.e.*, almost exactly 2° C. On August 27 they were again heated for six hours to 250° C., and slowly cooled. There was no further general change of zero point. On September 22 they were heated to 150° C. for 24 hours, and slowly cooled, and in November their fundamental and 50° points were determined.

To permit of the relatively high temperature of this anneal the thermometers were provided with an auxiliary chamber at the top of the stem, in addition to the one always present in Kew standards ranging to the boiling point. This chamber was sufficiently large to contain the necessary mercury to permit of the exposure of the thermometers to a temperature of about 300° C.

Of the 12 thermometers, six were used for this work, all having about the same dimensions and sensitiveness; Nos. 776, 778, and 780 read from below 0° to above 50° , and had the portion between 50° and 100° shortened by substitution of a small bulb for the upper part of the stem between about 52° and 98° . In Nos. 777, 779, and 782 the shortening was between $+2^{\circ}$ and 48° , a few degrees of stem being also available above and below the boiling point.*

The table on p. 229 shows their characteristic dimensions. They were all graduated into approximate degrees centigrade by Mr. Foster at Kew, in March, 1903, with the exception of No. 782, which was completed in January, 1905, to replace No. 781 accidentally broken.

* Thermometers Nos. 776 and 777 were only used in the later comparisons, the initial experiments being confined to the other four.

No.	Range.		Nature of stem.	Length of one degree.	Thickness of stem.	Centre of bulb to 0°.	0—50°.	50—100°.
	° C.	° C.		mm.	mm.	mm.	mm.	mm.
776	—2 to 51	and 98 to 102	Milk glass	8·05	5·45—5·50	55	402	53
777	—2 „ +1	„ 49 „ 107	„	7·30	5·55—5·60	62	30	365
778	—2 „ 53	„ 97 „ 102	„	7·60	5·75—5·80	60	380	73
779	—2 „ +1	„ 48 „ 105	„	7·40	5·95—6·05	58	44	370
780	—2 „ 52	„ 97 „ 102	Transparent	7·76	5·95—6·00	53	388	71
782	—1 „ +1	„ 48 „ 105	„	7·41	5·90—5·95	53	56	371

Each thermometer was then calibrated with threads of varying length. First a division into two parts was made with four different columns, approximately 50° C.; then a further subdivision of the principal 50° on each stem by two different 10°-columns. This gave with very considerable accuracy the calibration correction for every 10°—the points close to which comparisons were subsequently made. In addition two different 2°-columns were observed with their ends at every even two degrees throughout the scale. From the general mean of the 2°-calibrations perfectly independent values were found for the corrections at 10°, 20°, 30°, 40°, etc. In all cases where the length of the 2°-column was a close approximation to 2°, the results of the two independent calibrations agreed to within the limits of error of such work, and it was always possible to deduce the true calibration correction near the principal points—10°, 20°, 30°, etc.—to within two or three thousandths of a degree.

As in this type of thermometer, owing to the presence of the auxiliary chamber, increments of pressure on the bulb are not directly proportional to increments of temperature, a correction has to be determined to reduce the readings at any point to what it would have been had the point 50° C. been exactly half way between 0° and 100°. For this purpose observations of the 100° point of each of the thermometers were made in the Chappuis steam bath in both horizontal and vertical positions, and from these the pressure coefficient of each thermometer was calculated.

From these observations the following corrections were found for the six thermometers for the point 50° C., giving the amount to be added or subtracted from the reading to make the indications of the instrument comparable with the normal type having a continuous scale from 0° to 100° C. on p. 230.

The thermometers were compared with the standards of the laboratory and one or two other Tonnelot thermometers of French “verre dur,” the relation of whose indications to the hydrogen scale had been previously thoroughly

No. of thermometer.	Pressure correction for point 50° C.	Internal pressure coefficient, degrees per millimetre.
776	+0·029	0·0001676
777	—0·029	0·0001762
778	+0·026	0·0001670
779	—0·028	0·0001706
780	+0·036	0·0002259
782	—0·036	0·0002310

studied. Great care was taken to use the Kew standards under the same conditions as they would ordinarily be subjected to at Kew. It is known that the indications of a Kew standard depend on the treatment to which it has been subjected previous to use, and that a thermometer which had often been used over the higher part of its range would not follow the same law as to depression of its zero as one used but seldom.

In order to make strictly consistent the results obtained for the upper and lower parts of the range, got from the two different types of thermometers, in all cases the pairs Nos. 776 and 777, 778 and 779, and 780 and 782 were treated as single instruments, being always taken through precisely similar cycles of temperature change.

Dr. Chree, the Superintendent of the Observatory Department, was good enough to draw up a detailed memorandum as to the methods employed at Kew for their standards used in verification work, and it has been the object throughout this investigation to imitate this practice as closely as possible.

After finishing the calibrations, etc., and determining the zeros, the thermometers were placed in the comparison bath,* which was electrically heated and stirred continuously, and were slowly taken up from the ordinary temperature to the boiling point, the latter being attained in about five hours. The current was shut off after the boiling had continued about half an hour, and the bath was then allowed to cool slowly, with the thermometers in position. This treatment was repeated on three successive days. An interval of one clear day was then allowed, and the comparisons were begun on the following day, an observation of the zero being previously made, and a boiling point determination at the close.

* The bath consisted of two vertical cylindrical vessels, about 20 inches high, connected by horizontal cross tubes near the top and bottom. The whole vessel held about 20 litres of water. The stirring was continuous and very perfect throughout the whole of the larger tube, in which the thermometers were placed. The heating was electrical and could be arranged to give either a stationary temperature or any desired rate of slow rise or fall. It is hoped shortly to publish descriptions, with drawings, of this and other thermometric appliances used at the Laboratory in a special paper.

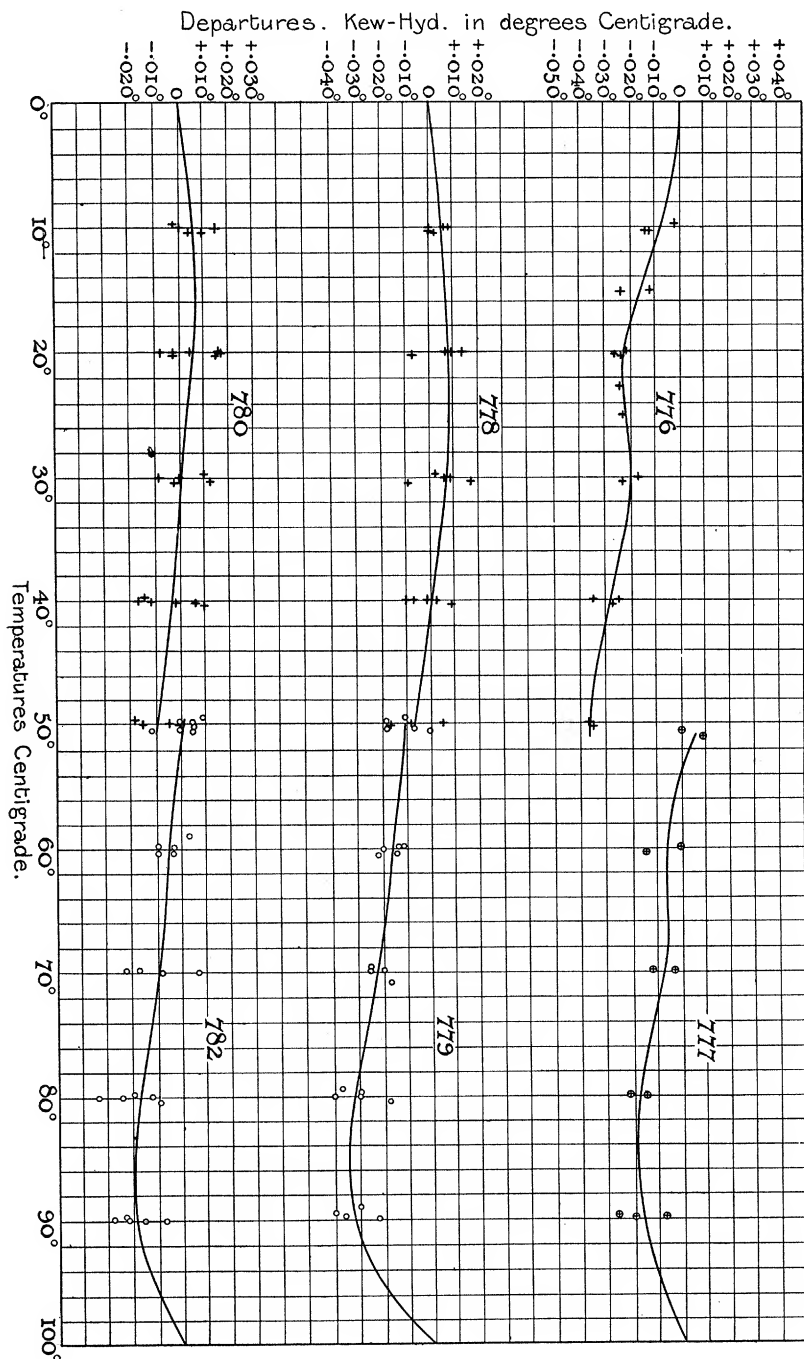
This treatment of heating to the boiling point, and allowing a clear day subsequent to this before commencing the observations, was repeated on each separate occasion, when a complete comparison was made. The sets of observations were made intentionally at intervals of several weeks to test the behaviour over a considerable period.

The following table gives a summary of the observations with thermometers Nos. 778 and 779, the different columns giving the mean values obtained, usually from two, sometimes from four, groups of readings, each group consisting of four observations of very slowly rising temperatures :—

Summary of Comparisons—Thermometers Nos. 778 and 779.

Date.	Zero position before observation.	Temp. on Kew scale.	Temp. on Hydr. scale.	Difference, Kew—hydr.
No. 778.				
December 1, 1905	-0·044	10·051	10·044	+0·007
		19·853	19·845	+0·008
		29·840	29·838	+0·002
		40·038	40·036	+0·002
		50·061	50·070	-0·009
February 6, 1906.....	-0·020	20·006	20·000	+0·006
		40·048	40·049	-0·001
		49·842	49·849	-0·007
April 30, 1906	-0·036	10·296	10·296	0·000
		10·377	10·375	+0·002
		20·232	20·240	-0·008
		30·389	30·398	-0·009
		40·067	40·077	-0·010
May 30, 1906	-0·002	50·214	50·231	-0·017
		20·052	20·039	+0·013
		30·201	30·184	+0·017
		40·257	40·248	+0·009
		50·089	50·084	+0·005
No. 779.				
December 1, 1905	+0·015	50·052	50·070	-0·018
		59·945	59·959	-0·014
		69·959	69·979	-0·020
		79·411	79·448	-0·037
		89·060	89·090	-0·030
February 6, 1906.....	+0·027	50·468	50·517	-0·049
		60·423	60·445	-0·022
		80·402	80·420	-0·018
April 30, 1906	+0·003	50·357	50·365	-0·008
		60·317	60·342	-0·015
		69·786	69·811	-0·025
		79·979	80·009	-0·030
		89·805	89·837	-0·032
May 30, 1906	+0·031	89·933	89·956	-0·023
		50·510	50·509	+0·001
		59·887	59·889	-0·012
		69·800	69·825	-0·025
		79·852	79·882	-0·030
		89·573	89·609	-0·036

The concordance of the different observations at any temperature is seen from the accompanying curves, in which all the observations are plotted.



The following example, selected at random from the note-book of observations, shows the order of accuracy of the individual comparisons, etc. :—

Comparisons of February 6, 1906, Thermometers Nos. 778 and 780 with Tonnelot No. 15,504 and Baudin No. 15,959. Zero readings after thermometers had been at room temperature, approximately 10° C., for several days, then for an hour in bath at about 20° C.

Zero corresponding to 20°—

Tonnelot No. 15,504 ... -0·007 Kew No. 778 -0·020
Baudin No. 15,959 +0·109 Kew No. 780 -0·060

No. 15,504.	Kew No. 780.	Kew No. 778.	No. 15,959.
First set of observations (J. A. H., observer).			
19·852	20·045	19·900	20·020
·870	·060	·910	·025
·900	·080	·950	·060
·920	·100	·955	·060
<hr/> 19·885	<hr/> 20·071	<hr/> 19·929	<hr/> 20·041
Second set of observations (W. H., observer).			
20·120	20·300	20·160	20·280
·140	·310	·170	·290
·155	·330	·190	·325
·165	·350	·195	·325
<hr/> 20·145	<hr/> 20·322	<hr/> 20·179	<hr/> 20·305

For the Kew thermometers the fundamental interval, as got from observations of the steam-point at the close of the day's work, was found—

For No. 778..... -100·012 Hence F. I. correction... = -0·012

And for No. 780 ... - 99·996 „ „ ... = +0·004

Reduction of Observations.

	Kew No. 778.	Kew No. 780.		Tonnelot 15,504.	Baudin 15,959.
Reading.....	19·929	20·071	Reading.....	19·885	20·041
Cal. cor.	-0·077	-0·274	Cal. cor.	+0·066	-0·011
Press. cor.....	+0·011	+0·014	Int. press.....	+0·027	+0·031
F. I. cor.	-0·003	+0·001	Ext. „ F. I. cor.	+0·000 -0·016	+0·000 +0·000
Zero cor.	+0·020	+0·060	Zero cor.	-0·007	-0·109
	19·880	19·872		19·955	19·952
			Hyd.	-0·085	-0·085
				19·870	19·867

Mean hydrogen temperature for first set = 19·869.

	Kew No. 778.	Kew No. 780.		Tonnellot 15,504.	Baudin 15,959.
Reading.....	20·179	20·322	Reading.....	20·145	20·305
Cal. cor.	-0·075	-0·275	Cal. cor.	+0·066	-0·011
Press. cor.....	+0·011	+0·014	Int. press.....	+0·027	+0·031
F. I. cor.	-0·003	+0·000	Ext. „	+0·000	+0·000
Zero cor.	+0·020	+0·060	F. I. cor.	-0·016	+0·000
	20·132	20·121	Zero cor.	-0·007	-0·109
			Hyd.	20·215 -0·085	20·216 -0·085
				20·130	20·131

Mean hydrogen temperature for second set = 20·131.

	Kew No. 778.	Kew No. 780.	
Mean of two sets	20·006	19·998	Mean hydrogen temperature
Departure from hydrogen	+0·006	-0·002	for mean of both sets
			= 20·000.

It will be observed that, owing to calibration and zero corrections of considerable magnitude, the readings of the two standards differed at this temperature about 0°·16 C., but when the various corrections were applied in accordance with the usual procedure the concordance between the two thermometers was very satisfactory.

Owing to the fact that four out of the six Kew thermometers have milk-glass back to the stems it is only possible to read them in one position, *i.e.*, divisions at the front, and therefore no elimination of any want of verticality in the bath is possible by the method of turning round the thermometer usually employed in the best work. For the same reason only one position is possible for the zero observations. In the zero bath great attention was paid to the strict alignment of the spring clips holding the thermometer in the ice, but in the comparisons, owing to the surging caused by the stirrer, slight motions of the thermometers were inevitable.

A tilt of 1° from the vertical position would in the Kew thermometers cause a parallax error of about 1/20 mm. or 0°·007 C.

The whole of the observations were plotted on a large scale, a reproduction of which is given in the figure, and from a consideration of the individual values, curves were drawn representing the mean departure of each thermometer from the hydrogen scale throughout its range. From these curves the following values were read off:—

Mean Departure from Hydrogen Scale.

	No. 776.	No. 778.	No. 780.	Mean.
0	0·000	0·000	0·000	0·000
10	-0·008	+0·004	+0·006	+0·001
20	-0·022	+0·007	+0·006	-0·003
30	-0·020	+0·006	+0·001	-0·004
40	-0·028	-0·000	-0·003	-0·010
50	-0·035	-0·008	-0·009	-0·017
	No. 777.	No. 779.	No. 782.	-0·010
50	0·000	-0·010	-0·000	-0·003
60	-0·005	-0·015	-0·005	-0·008
70	-0·010	-0·022	-0·010	-0·014
80	-0·015	-0·033	-0·018	-0·022
90	-0·020	-0·032	-0·020	-0·024
100	0·000	0·000	0·000	0·000

If the behaviour of the pairs of thermometers were absolutely consistent, the departure from the hydrogen scale of the low-range and high-range types at 50° C. should be identical. The discontinuity is, however, very small except in the case of Nos. 776 and 777. The differences in the last column of the table above are many of them of the same order as the accidental errors of observation in the best work. Thus for example in his "Études sur le thermomètre à gaz" during some elaborate comparisons of the primary standard thermometers Nos. 4428, 4429, 4430 and 4431, on which the "verre dur" scale depends, Chappuis found that in one series at 60° C., No. 4428 read 0°008 *higher* than the mean of four, and No. 4429 0°012 lower, while in a second series the positions were reversed, No. 4428 reading 0°008 *lower* than the mean, and 4429 the same amount *higher*.

In addition to the work on the new special thermometers a systematic comparison was also made of a number of old Kew standards of the ordinary construction divided to whole degrees Fahrenheit. A selection was made of thermometers of widely differing types, which had necessarily been subjected to varying treatment. The zeros of some of them had been displaced appreciably from their original positions. After applying the usual zero-correction to all the observations, but no calibration-interval correction, the results in the table on p. 236 were obtained for the divergence of each from the hydrogen scale.

Of these thermometers No. 560, a high-range thermometer, had a considerable zero error, having been frequently used in the upper part of its scale, and No. 41 was of a somewhat unusual type, and much older than the others, with a transparent stem and spherical bulb. It was formerly the

Old Kew Standards.
Differences Kew — Hyd. (expressed in degrees Centigrade).
No fundamental-interval correction applied.*

	No. 544.	No. 560.	No. 722.	No. 728.	No. 41.	No. 686.
Range	— 40° to 215° F.	— 10° to 555° F.	— 45° to 222° F.	— 20° to 122° F.	0° to 220° F.	— 20° to 225° F.
Thickness of stem	7·5	7	7	6·5	(Spherical bulb, transparent stem)	7·5
Length of 1° in mm.	2·1	1	1·9	2·7	2·2	1·9
Date of completion	September, 1877	June, 1878	July, 1895	March, 1896	July, 1852	January, 1889
Maker	T. W. Baker	T. W. Baker	J. Foster	J. Foster	—	J. Foster
0° C.	+ 0·00	+ 0·00	+ 0·00	+ 0·00	— 0·00	+ 0·00
10	+ 0·01	+ 0·01	+ 0·01	+ 0·02	— 0·01	+ 0·02
20	+ 0·02	+ 0·02	+ 0·02	+ 0·03	— 0·01	+ 0·05
30	+ 0·03	+ 0·03	+ 0·01	+ 0·03	— 0·02	+ 0·07
40	+ 0·03	+ 0·03	+ 0·02	+ 0·03	— 0·03	+ 0·10
50	+ 0·04	+ 0·04	+ 0·04	+ 0·03	— 0·06	+ 0·12
60	+ 0·04	+ 0·03	+ 0·05	+ 0·02	— 0·08	+ 0·13
70	+ 0·05	+ 0·03	+ 0·06	+ 0·01	— 0·09	+ 0·14
80	+ 0·06	+ 0·05	+ 0·06	+ 0·01	— 0·08	+ 0·15
90	+ 0·06	+ 0·04	+ 0·05	+ 0·01	— 0·05	+ 0·15

* The usual Kew practice would be to apply to any thermometer, new or old, in which a fundamental interval error was observed, as, for example, No. 686 above, the requisite corrections throughout the scale.

property of Mr. G. Griffith, of Harrow, and was obtained for the laboratory by the kindness of Mrs. Griffith in 1904. It will be seen that its scale is almost absolutely identical with that of the thermometer examined by Wiebe.

The above readings apply to the thermometers assuming their fundamental interval to be correct. As, however, the departure from the hydrogen scale is of the opposite sign in the first four instruments to that found in the new standards, it was thought desirable to make measurements of the fundamental intervals of some of them. No. 544 was found to need a fundamental interval correction of $-0^{\circ}07$, No. 560 of $-0^{\circ}06$, No. 722 of $-0^{\circ}03$ and No. 686 of $-0^{\circ}17$. Applying these to the results in the above table, we have as the *true* departure of the scale of these from the hydrogen scale:—

Old Kew Standards. True Departures from Hydrogen Scale.

Temp. ° C.	No. 544.	No. 560.	No. 722.	No. 686.
0	+0·00	+0·00	+0·00	+0·00
10	+0·00	+0·01	+0·01	+0·00
20	+0·00	+0·01	+0·01	+0·03
30	+0·00	+0·01	+0·00	+0·02
40	+0·00	+0·00	+0·00	+0·03
50	+0·00	+0·01	+0·02	+0·03
60	+0·00	-0·01	+0·03	+0·02
70	+0·00	-0·01	+0·03	+0·02
80	+0·00	-0·00	+0·03	+0·02
90	+0·00	-0·01	+0·02	+0·01
100	+0·00	0·00	+0·00	+0·00

When it is remembered that the length of 1° C. on these thermometers only covers from 2 to 4 mm. and that the divisions are relatively thick, it will be seen that these divergences are wholly negligible, and that within the limits of error attainable all these thermometers used in the normal way by the “fixed zero” method give a close approximation to the hydrogen scale.

Before commencing the first of the normal series of comparisons of the special standards it was deemed to be a matter of considerable interest to make a series of comparisons when the thermometer zeros were in the relatively high position they had attained after the instrument had been a long time at the ordinary temperature. The observations in this set were very complete and extended over two days. Zeros were taken before commencing work, after the comparisons at 50° on the first day, after a second comparison at the same temperature on the second day, and after the steam-points at the conclusion of the observations. From these were obtainable all the data required to calculate the observations, *first* by the ordinary method,

applying the *fixed* zero determined at the commencement, and *second* applying a *depressed* zero calculated by interpolation, from the observations after 10°, 50° and 100°. The fundamental interval correction determined from the steam-point values taken at the finish is, however, notably different in the two systems. Thus, for example, the fundamental interval of No. 778 on the *fixed* zero method is 100°·001, and on the *depressed* 100°·085. The table gives a summary of the differences, Kew—Hyd., obtained by calculating out the same set of values on the two systems.

Summary of Observations calculated by both Methods.

	Temp.	Ordinary method fixed zero after 10°.		Mean departure ordinary method.	Depressed zero method calculated from zeros observed after 10°, 50° and 100°.		Mean departure depressed zero method.
		No. 778.	No. 780.	Kew—Hyd.	No. 778.	No. 780.	Kew—Hyd.
Sept. 11, 1905	°						
	10	+0·008	+0·000	+0·004	0·000	—0·005	—0·002
	20	+0·009	—0·008	+0·000	—0·003	—0·006	—0·004
	30	+0·009	—0·009	+0·000	—0·006	—0·000	—0·003
	40	—0·007	—0·017	—0·005	—0·024	—0·002	—0·013
"	50	—0·011	—0·036	—0·024	—0·030	—0·013	—0·021
Sept. 12, 1905		No. 779.	No. 782.		No. 779.	No. 782.	
	50	—0·018	+0·004	—0·007	—0·037	—0·014	—0·025
	50	—0·019	+0·004	—0·007	—0·001	—0·008	—0·005
	50	—0·011	+0·008	—0·002	+0·015	—0·006	—0·004
	60	—0·020	+0·002	—0·009	+0·001	—0·008	—0·003
	70	—0·017	+0·006	—0·005	—0·002	—0·001	—0·002
	80	—0·039	—0·013	—0·026	—0·029	—0·018	—0·024
	90	—0·039	—0·007	—0·023	—0·034	—0·009	—0·022

In judging of the results obtained with this series it must be remembered that with thermometers in their virgin state the zero movements are relatively large, and that the time of exposure to any temperature higher than that to which they have been long subjected has a marked influence on the results obtained. A very long period of rest is necessary to completely eliminate the effects of the unavoidable warming of the bulbs in the severing of columns for calibration purposes, and it is not certain that the effect of this warming would be identical in all cases. In so far as can be judged from a single set of observations with the thermometers after lying by for a considerable period, there appears to be almost complete agreement between results of the two methods of using the thermometers, these being in the state when differences would be most likely to be manifested. The results given by

the thermometers do not differ appreciably from what is obtained when in the more normal condition after exposure to varied temperature ranges.

The main conclusions of the work are therefore:—

(1) The departure of the natural scale of the “Kew” mercury-in-glass thermometer from the international hydrogen scale is very small at all temperatures.

(2) For measurement of temperature *differences* over ordinary ranges such as in calorimetry, the results obtained directly or indirectly from a Kew standard may be considered as hydrogen temperatures without application of any correction.

(3) In some instances when defining the temperature at which certain standards have their definite value, such as, for example, the temperature 62° F. for the British standard yard, the temperature scale to which the measurement referred was not definitely specified. This research renders it probable that if the instrument were a good English glass thermometer approximating to a Kew standard, the error made in considering its indications as identical with the hydrogen scale would be within the limits of accuracy of length measurements.

(4) For the ordinary ranges of meteorological and clinical thermometers reading to 0°·1 F., many thousands of which have been verified at Kew annually for many years past, the temperatures as given on the Kew certificate may be considered as hydrogen temperatures.

(5) The table appended gives the mean departure from the hydrogen scale of the “Kew” scale of temperature as observed in this investigation, the figures being rounded to the most probable 0°·005 C. For comparison purposes the figures for French “Verre Dur” and for Jena “Glass 16'''” are added in parallel columns, it being understood that each glass is treated in the manner prescribed for it: the Kew glass being a “fixed zero” scale and the other two “movable zero.”

Differences in Degrees Centigrade.

	Kew glass. $T_{\text{Kew}} - T_{\text{Hyd.}}$	Verre dur. $T_{\text{VD}} - T_{\text{Hyd.}}$	Jena glass. $T_{16'''} - T_{\text{Hyd.}}$
0	+0·000	+0·000	+0·000
10	+0·000	+0·052	+0·056
20	+0·000	+0·085	+0·093
30	-0·005	+0·102	+0·113
40	-0·010	+0·107	+0·120
50	-0·010	+0·103	+0·116
60	-0·010	+0·090	+0·103
70	-0·015	+0·072	+0·083
80	-0·020	+0·050	+0·058
90	-0·025	+0·026	+0·030
100	-0·000	+0·000	+0·000

In conclusion, I must express my indebtedness to the Director of the Laboratory, Dr. Glazebrook, at whose instigation this work was carried out, to Dr. Chree, Superintendent of the Observatory Department, for much valuable information, and to Mr. W. Hugo, who was responsible for the whole of the observational work of the calibrations and also assisted in the comparisons.

Determinations of Wave-length from Spectra obtained at the Total Solar Eclipses of 1900, 1901 and 1905.

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(Abstract.)

This paper gives the wave-lengths deduced from measures of a number of photographs of the chromosphere and corona obtained in three eclipse expeditions from the Royal Observatory, Greenwich. The spectra extend from wave-length 3300 to 5875.

Nearly all the brighter lines of the chromosphere are identified with practical certainty, the observed wave-length differing in very few cases by 0.1 tenth-metre from the line with which it is identified. The identification was principally made by comparison with the spark spectra of Exner and Haschek, Sir Norman Lockyer's results being used for "enhanced" lines. For comparison, the intensities of the corresponding lines in the spark, arc, and solar spectra are given, obtained from various published sources.

The wave-lengths and intensities of a number of lines in the spectrum of the higher chromosphere obtained at Sfax in 1905 are also given.

The wave-lengths and intensities of the lines observed in the spectra of the corona at the three eclipses are also given.

The paper is purely descriptive and shows in detail the relation between the chromospheric spectrum and those of the spark and arc, but does not attempt to assign physical causes to the differences and resemblances.
